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Is There an Indication for Computed Tomography and Magnetic Resonance Imaging in the Evaluation of Coronary Artery Bypass Grafts?

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Abstract: This meta-analysis evaluates the diagnostic accuracy of multidetector computed tomography (MDCT) and magnetic resonance imaging (MRI) for bypass graft occlusion and stenosis detection compared with coronary angiography in post–coronary artery bypass graft patients. The indication for noninvasive imaging in post–coronary artery bypass graft patients with these techniques is discussed.

Overall, MRI had significantly lower sensitivity (81%) and specificity (91%) for occlusion detection than MDCT (96% and 98%, respectively). Only 2 studies assessed the accuracy of stenosis detection with MRI. Stenosis detection with MDCT had a pooled sensitivity of 89% and specificity of 97%. Multidetector computed tomography is therefore superior to MRI for the noninvasive detection of coronary bypass graft occlusion and stenosis. For stenosis detection, the accuracy of MDCT is, however, not sufficient to warrant a wide clinical use. The remaining indication for MRI-guided bypass graft assessment is in combination with myocardial evaluation such as magnetic resonance perfusion, wall motion, and stress test as a "one-stop-shop" procedure.

Key Words: coronary artery bypass graft, multidetector computed tomography, magnetic resonance imaging, diagnostic accuracy

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The occurrence of coronary artery bypass graft (CABG) disease and occlusion is common and increases over the years.[1] Vein grafts have a higher occlusion rate compared with arterial grafts.[1–4] Coronary angiography (CAG) is the gold standard in the diagnostic workup of CABG patients but has some well-known disadvantages. First, it is not without risks, and it is relatively expensive.[5] Second, 3-dimensional (3D) anatomical orientation of the bypass graft in relation to the chest, mediastinum, pericardium, and epicardial vessels, including the venous system, is lacking or poor with selective catheterization. And third, visualization of CABG lumina requires selective catheterization of the graft, which is regarded as especally difficult for gastroepiploic artery grafts.[6,7] The orifices of these grafts are not in well-known anatomical positions as a result of which selective catheterization can be hampered. Noninvasive diagnostic alternatives have been searched for because of these disadvantages of CAG. Both magnetic resonance imaging (MRI) and multidetector computed tomography (MDCT) have been suggested and extensively studied for their value to serve this goal.

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Coronary artery bypass grafts are more easily assessed using noninvasive techniques because they are less mobile and have larger diameters than most native coronary arteries.[8–10] However, the presence of surgical wires, clips, and heavy calcifications makes the evaluation of CABGs with these techniques difficult. Furthermore, distal anastomoses are more sensitive to motion artifacts than proximal anastomoses and are therefore not always assessable.

Both modalities have their advantages and disadvantages. One recent meta-analysis has been published in which the diagnostic accuracy of MDCT was evaluated, but no review or meta-analyses have been published, which systematically pooled and compared MRI and MDCT data in post-CABG patients.[11] Magnetic resonance imaging enables visualization of the coronary bypass grafts and obtains flow information without the use of radiation.[12–14] The latest MDCT scanners have both a high temporal and spatial resolution, which enables stenosis detection with high accuracy.[15,16] The purpose of this systematic review and meta-analysis is to evaluate the existing evidence of the diagnostic accuracy of MDCT and MRI for detection of bypass occlusion and stenosis compared with CAG in post-CABG patients. The accuracy of the most recent and advanced scanners and scanning protocols of MDCT and MRI are compared, and the indication for noninvasive imaging in post-CABG with these techniques is discussed.

MATERIALS AND METHODS

Literature Review

A computerized search was performed to identify relevant articles published before 1 August 2007 in MEDLINE and EMBASE. With the assistance of a librarian, the following strategy was undertaken in MEDLINE for MDCT: "tomography, x-ray computed" [MeSH] *and* (coronary angiograph* [all fields] *or* "heart catheter*" [all fields]) *and* ("coronary artery bypass" [MeSH terms] *or* "gastroepiploic artery" [MeSH terms] *or* gastroepiploic artery [text word] *or* "myocardial reperfusion" [all fields]), combined with the diagnostic filter specified in PubMed under clinical queries (broad search). For MRI, "magnetic resonance imaging" was used as MeSH term and as text word. The search was limited to articles concerning humans and articles with abstracts. In EMBASE, we used "multidetector-computed-tomography" *or* "nuclear-magnetic-resonance-imaging" *and* "bypass-surgery "(in DEM) *and* "angiography" *and* "article" (document type) *and* "journal" (publication type).

Two reviewers (R.D. and T.P.W. for MRI; R.D. and H.J.Z.L. for MDCT) independently manually cross-referenced bibliographies in all original articles and narrative reviews and editorials on the subject for any articles not identified by the electronic search. All languages were considered. If the article was in a language other than English, German, or French, it was officially translated. The complete search yielded 351 articles (141 for MRI and 210 for MDCT) (Fig. 1).

Eligibility Criteria

Studies assessing the value of MDCT or MRI in post-CABG patients were searched for. When an article described a mixed population, including also non-CABG patients, but a separate analysis for CABG patients was reported, the study was included in the search. Articles were furthermore included when (*a*) all patients underwent CAG as a reference standard (to avoid partial verification bias or referral bias) and (*b*) absolute numbers of cases were reported or at least 2 × 2 tables could be deducted; when diagnostic accuracy was reported but absolute numbers were not, the corresponding author was contacted, and the study was included if the absolute numbers were provided. Studies were excluded when (*a*) 10 or less than 10 patients were included, as smaller studies are more likely to suffer from selection bias[17]; (*b*) multiple reports were published on the same study population (in this case, the publication with the largest study group was included in the analysis; in case of doubt about duplicate publications, the primary author was contacted); (*c*) the primary aim of the study was the evaluation of a techcnical/postprocessing protocol; (*d*) the article was a review or editorial; or if (*e*) an MRI scanner of less than 1.5 T was used because this would result in an unfair comparison with MDCT.

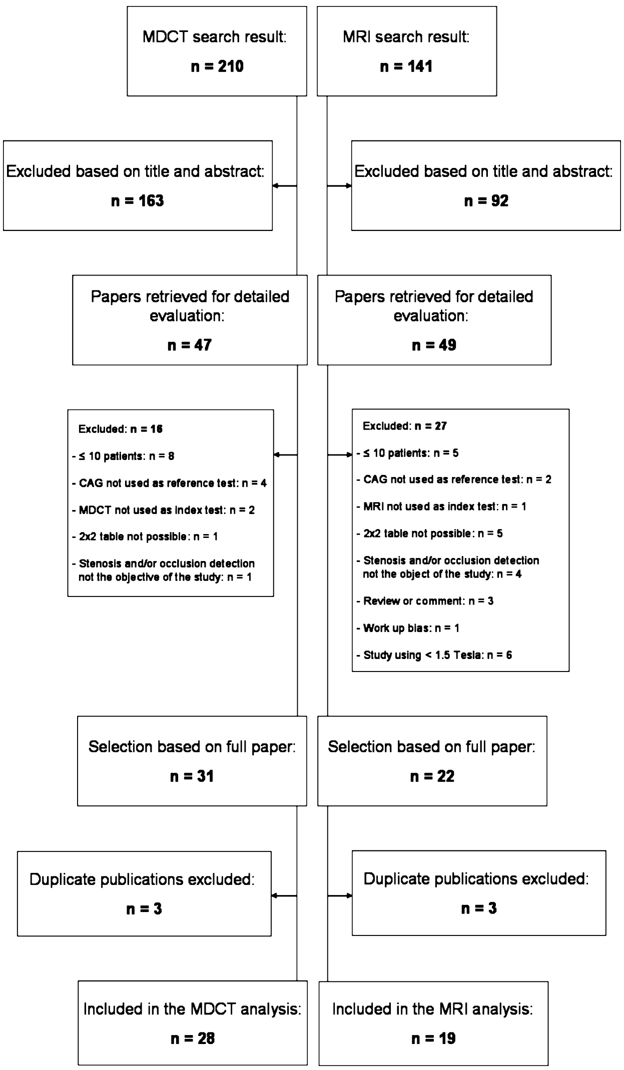

FIGURE 1. Flow chart of literature search.

Data Collection and Quality Assessment

Two reviewers (R.D. and H.J.Z.L.) independently selected both MDCT and MRI articles based on title and abstract; if one of the reviewers considered the study potentially eligible, the full article was evaluated. Study quality was assessed independently by 2 observers (R.D. and T.P.W. for MRI; R.D. and H.J.Z.L. for MDCT) using the QUADAS tool[18]; disagreement was resolved by arbitration. This evidence-based tool was developed specifically to assess the quality of diagnostic accuracy studies and included 14 quality items.

The following study descriptives were extracted: population descriptives (age, male-to-female ratio, time after surgery, patient group (symptomatic or asymptomatic), study design, type of MDCT and/or MRI scanner used, rotation times (MDCT), scanning sequence (MRI), heart rate during scan (MDCT), number of evaluable and nonevaluable patients and grafts, type of analysis, and diagnostic accuracy numbers (true positives, false positives, true negatives, and false negatives). For consistency of the data across the articles, occluded grafts were considered as positive and open grafts as negative. In case the original article did not provide enough information to be included in the meta-analysis, the primary investigator was contacted for more detailed information.

Also for consistency, analyses including all bypass grafts were considered as superior to analyses including only the assessable bypass grafts. Therefore, when the article itself did not provide these analyses, but there was sufficient information in the article to compute the diagnostic value of MDCT or MRI including those nonassessable grafts, the sensitivity and specificity as recalculated by our own data instead of the reported sensitivity and specificity in the article were used. In doing this, any nonassessable graft was considered as negative (open).

Statistical Analysis

Differences in study characteristics between the 2 techniques were tested using χ^2 statistics for proportions and parametric (Student *t* test) or nonparametric statistics (Mann-Whitney *U* test) for continuous variables. Evaluation of the diagnostic odds ratio (DOR) was performed to evaluate the distribution of diagnostic accuracies between studies and between techniques. Diagnostic odds ratio is calculated by [sensitivity / (1 − sensitivity)] / [(1 − specificity) / specificity].

Exploration of Heterogeneity

Primary outcome of this meta-analysis was diagnostic accuracy for bypass graft occlusion detection; secondary outcome was bypass stenosis detection (≥50% luminal diameter reduction). Individual study sensitivities and specificities with 95% confidence intervals (CIs) were plotted to identify heterogeneity between studies. Heterogeneity was explored using the Higgins and Thompson test, calculating the I^2 statistic.[19] This statistic uses the conventional Cochran *Q* statistic to calculate the percentage of total variation across studies that can be attributed to between-study heterogeneity.[19] Explanations for heterogeneity within diagnostic techniques were analyzed using stratification.

Assessment of Publication Bias

The presence of publication bias was visually assessed by producing a funnel plot of the natural logarithm of the DOR against the effective sample size, as proposed by Deeks et al[20] and tested using Egger's regression test.

Assessment of Diagnostic Accuracy

A bivariate analysis of sensitivity and specificity was performed as described by Reitsma et al.[21] In short, this analysis includes both sensitivity and specificity when comparing the diagnostic value of 2 techniques, as these are often negatively correlated. In the bivariate model, one can specifically test whether there is a difference in sensitivity, specificity, or both and examine the effect of other variables on this difference.

Data were analyzed in SPSS 14.0 (SPSS Inc, Chicago, Ill), Stata SE version 8.0 (STATA Corp, College Station, Tex), Winpepi (Sagebrush Press, Salt Lake City, UT), Meta-DiSc 1.4 (Bristol, UK),[22] and MLWin 2.02 (Madrid, Spain).

RESULTS

Search Results

The search yielded 351 potential articles for either MDCT or MRI. Based on title and abstract, 96 articles were selected to be evaluated (Fig. 1). No articles were found in which MDCT and MRI were compared within the same patient population. In total, 5 primary investigators were contacted for more details on 7 different articles. In total, 47 articles were included, 28 for MDCT[15,16,23–48] and 19 for MRI.[49–67] Six articles using MRI of less than 1.0 T were excluded, including one of the first publications from 1988 using a 0.26-T MRI.[68]

Exploration of Heterogeneity in Occlusion Detection

Patients included in the MDCT studies were on average 2 years older compared with the patients included in the MRI studies (65 vs 63 years, $P = 0.03$). In MDCT studies, significantly more symptomatic patients were included compared with MRI studies ($P = 0.03$). Other variables (quality of articles, language of articles, study design, percentage male, mean time between surgery and scan, mean occlusion rate of bypass grafts) were not significantly different between studies of the 2 techniques.

Sensitivity and specificity rates of all articles assessing the value of MDCT in post-CABG patients were homogenous. High-quality studies (QUADAS ≥12) were moderately homogeneous, whereas low-quality studies (QUADAS <12) were highly homogeneous. Study design, type of MDCT scanner, and disease preference did not show heterogeneity.

Among all included MRI studies, sensitivities were homogeneous, whereas specificities were heterogeneous for occlusion detection. Studies using magnetic resonance angiography (MRA) with gadolinium as contrast agent were homogeneous both in sensitivities and specificities. Studies using other MRI scanning sequences were homogeneous for sensitivity but heterogeneous in specificity.

Assessment of Publication Bias

The funnel plot depicted clear evidence for publication bias, and none of the intercepts included 0 (CI around the intercept of MDCT studies was 0.4–1.2, $P < 0.001$; for MRI studies, 2.2–3.2, $P = 0.004$).

MDCT Studies

For MDCT, 25 articles were in English, 1 in Italian, 1 in Chinese, and 1 in Polish. The mean quality score of the included articles was 11.8 (SD, 1.5), and all articles were published between 2001 and 2007. Sixteen articles had a prospective consecutive study design, and 12 articles had a prospective nonconsecutive study design. In total, 1320 patients were included (82% men), with a mean age of 65.0 years (SD, 3.0 years) (Table 1A). A total of 3637 bypass grafts wereexamined after a median time of 7.6 years (range, 0.5–10 years) after CABG surgery. In total, 60% venous bypass grafts and 40% arterial bypass grafts were included, with a median occlusion rate of 21% (range, 1%–44%). Nineteen articles reported details on the type of patients included: 18 articles included symptomatic patients and 1 article included asymptomatic patients for the evaluation of graft patency after CABG surgery at least 10 years previously.[39]

The reported sensitivities for occlusion detection using MDCT ranged from 69% to 100%, with a number of excluded bypass grafts ranging from 0% to 25% (Table 2A). Specificity for occlusion detection ranged from 95% to 100%. The DOR for all studies are plotted in Figure 2. The overall 95% CI of all DORs for occlusion detection using MDCT was 1065 (Fig. 2A). Seventeen studies reported the accuracy of MDCT for stenosis detection, in which the sensitivity ranged from 33% to 100%, specificity ranged from 85% to 100%, and the number of excluded bypass grafts ranged from 0% to 38%.

Occlusion Detection

Overall sensitivity and specificity for all 28 MDCT studies were 96% (95% CI, 95%–97%) and 98% (95% CI, 98%–99%), respectively. Sensitivity for studies using 4-slice MDCT (n = 8) was 95% (95% CI, 91%–97%); for 16-slice (n = 12), 96% (95% CI, 94%–98%); and for 64-slice (n = 8), 98% (95% CI, 95%–99%). Specificity was the same for all scanners: 98% (95% CI, 97%–99%).

Stenosis Detection

Seventeen MDCT articles, including 2357 bypass grafts, included numbers on the accuracy of stenosis detection.[15,23–26,28–32,34,35,37,38,40,43,45] One article defined significant stenosis as a lumen diameter reduction of more than 70%,[29] and 16 articles defined significant stenosis as lumen diameter reduction of more than 50%.[15,23–26,28,30–32,34,35,37,38,40,43,45] The pooled sensitivity was 89% (95% CI, 84%–92%), and specificity was 97% (95% CI, 96%–98%). Seventeen articles using a 16- or 64-slice MDCT scanner performed somewhat better (pooled sensitivity, 92% [95% CI, 87%–95%]; pooled specificity, 97% [95% CI, 97%–98%]).[15,16,23–26,28,31,32,35,38,40,41,43,45–47]

Four included MDCT studies reported the accuracy of stenosis detection in native coronary segments.[23,26,38,46] The number of segments that were nonassessable ranged from 3% to 31%. Overall sensitivity was 85% (95% CI, 81%–89%), and specificity was 82% (95% CI, 79%–84%).

MRI Studies

For MRI, 12 articles were in English, 5 in German, 1 in French, and 1 in Japanese. Included articles were published between 1989 and 2004. Nine of the 19 included articles were published before the year 2000. The mean quality score was 11.7 (SD, 1.9). The study design was known in 17 articles: 9 articles had a prospective, consecutive design; 8 articles had a prospective nonconsecutive study design. The articles included 492 patients (86% men), with a mean age of 62.9 years (SD, 2.8 years) (Table 1B). A total of 1215 bypass grafts after a median

TABLE 1. Study Characteristics

A. MDCT

Study(Author, Reference)	Evaluable Patients	Male,%	Age*	Heart Rate (Mean), bpm	No. Evaluable Bypass Grafts	Venous Grafts, %	Arterial Grafts, %	Population	Time Since Surgery*	Occlusion Rate, %	Quality Score
4-Detector MDCT											
Ropers et al[37]	65	82	67	72	182	89	11	NA	7.6	32	11
Pasowicz et al[36]	57	70	59	NA	187	89	11	Symptomatic	3.1	30	11
Yoo et al[48]	42	76	71	NA	125	44	56	NA	NA	4	11
Ko et al[29]	39	74	60	NA	115	47	53	NA	1.2	13	10
Nieman et al[34]	24	83	64	64	40	58	42	Symptomatic	9.6	26	13
Marano et al[30]	57	95	65	NA	122	22	78	NA	4.8	23	12
Rossi et al[39]	47	94	67	62	116	75	25	Asymptomatic	10	32	11
Moore et al[33]	50	76	63	64	150	75	25	Symptomatic	7.8	31	10
4-, 16-Detector MDCT											
Schuijf et al[42]	11	NA	NA	NA	21	76	24	Symptomatic	NA	NA	12
Imagawa et al[27]	32	NA	NA	NA	81	7	93	NA	NA	1	8
8-Detector MDCT											
Song et al[44]	50	78	69	NA	170	9	91	NA	0.5	2	12
16-Detector MDCT											
Schlosser et al[41]	48	76	65	64	131	69	31	NA	5.6	16	11
Song et al[45]	56	82	64	58	152	68	32	Symptomatic	7.6	24	10
Martuscelli et al[31]	96	83	62	58	251	66	34	Symptomatic	7.0	20	13
Chiurlia et al[25]	52	87	63	58	165	71	29	NA	7.9	33	12
Schuijf et al[43]	22	NA	NA	NA	62	79	21	Symptomatic	NA	NA	13
Trigo Bautista et al[47]	38	76	67	62	98	62	38	Symptomatic	NA	17	12
Salm et al[40]	25	96	67	64	67	79	21	Symptomatic	9.2	17	10
Anders et al[15]	32	91	67	63	93	80	20	Symptomatic	NA	30	12
Stauder et al[46]	20	NA	NA	67	50	68	32	Symptomatic	4.8	NA	13
Burgstahler et al[16]	13	77	62	68	43	74	26	Symptomatic	NA	37	10
Bartnes et al[24]	45	76	NA	NA	156		70	NA	2.2	11	13
Andreini et al[23]	96	77	63	61	216	47	53	Symptomatic	8.0	21	14
64-Detector MDCT											
Pache et al[35]	31	84	68	63	93	76	24	Symptomatic	7.7	44	12
Ropers et al[38]	50	76	67	59	138	72	28	Symptomatic	8.8	28	14
Meyer et al[32]	138	88	68	63	379	64	36	Symptomatic	8.0	21	14
Dikkers et al[26]	34	85	64	61	69	25	75	Symptomatic	6.7	15	14
Jabara et al[28]	50	92	64	60	147	68	32	Symptomatic	8.1	19	13
Total	S 1320	M 82.3	M 65.0	M 62.7	S 3637	M 60.3	M 39.7		m 7.6	m 21.0	M 11.8

B. MRI

Study (Author, Reference)	Evaluable Patients	Male,%	Age*	No. Evaluable Bypass Grafts	Venous Grafts, %	Arterial Grafts, %	Population	Time Since Surgery*	Occlusion Rate, %	Quality Score
1.5 T										
Aurigemma et al[50]	20	NA	NA	45	91	9	Asymptomatic	NA	27	12
Wicke et al[63]	20	90	62	52	100	0	Asymptomatic	0.25	21	10
Ambrosi et al[49]	20	100	66	42	76	24	Symptomatic	NA	31	11
Okamura et al[58]	35	86	61	92	62	38	NA	NA	2	7
Vrachliotis et al[62]	15	73	64	45	64	36	Symptomatic	9.3	32	13
Von Smekal et al[61]	18	100	60	41	63	37	Asymptomatic	1.3	18	12
Wintersperger et al[64]	27	96	58	76	63	37	NA	2.2	21	12
Kalden et al[55]	38	84	66	97	80	20	Symptomatic	6.3	23	12
Boehm et al[51]	12	67	65	17	29	71	Asymptomatic	0.02	0	9
Molinari et al[57]	18	72	66	49	59	41	Symptomatic	4.4	24	14
Engelmann et al[53]	16	100	58	55	69	31	Asymptomatic	2.1	24	14
Wittlinger et al[65]	29	83	66	74	76	24	Symptomatic	5.6	22	14
Ishida et al[54]	24	85	64	24	0	100	Asymptomatic	0.07	0	13
Vetter et al[60]	22	73	59	22	0	100	Asymptomatic	0.02	5	11
Wittlinger et al[66]	25	80	62	63	75	25	NA	5.3	25	11
Wittlinger et al[67]	34	88	62	82	78	22	Symptomatic	7.3	22	14
Bunce et al[52]	25	100	63	79	71	29	Symptomatic	6.7	14	13
Langerak et al[56]	69	84	66	166	75	25	Symptomatic	9.3	25	11
Salm et al[59]	25	88	65	46	79	21	Symptomatic	11	60	10
Total	S 492	M86.0	M62.9	S 1215	M 63.7	M 36.3		m 4.8	m 22.0	M 11.7

*Given in years (mean).

bpm indicates beats per minute; NA, not available; symptomatic, patients suspected of having ischemic heart disease or angina pectoris; asymptomatic, patients without complaints of chest pain; S, sum; M, mean; m, median.

TABLE 2. Study Results

A. MDCT

Study (Author, Reference)	Time Between Tests (Mean, d)	Occlusion Detection, %			Stenosis Detection, %		
		Unevaluable	Sensitivity	Specificity	Unevaluable	Sensitivity	Specificity
4-Detector MDCT							
Ropers et al[37]	3*	0	97	98	38	75	92
Pasowicz et al[36]	5*	0	92	95	NA	NA	NA
Yoo et al[48]	91*	0	100†	98†	NA	NA	NA
Ko et al[29]	17	0	93	99	4	67	98
Nieman et al[34]	11*	8	100‡	97‡	7	70‡	91‡
Marano et al[30]	5	0	93	98	33	80	96
Rossi et al[39]	183*	9	100	100	NA	NA	NA
Moore et al[33]	26	0	91	100	NA	NA	NA
4- and 16-Detector MDCT							
Schuijf et al[42]	NA	0	100	100	NA	NA	NA
Imagawa et al[27]	NA	0	100†	98†	NA	NA	NA
8- Detector MDCT							
Song et al[44]	7*	0	100	99	NA	NA	NA
16-Detector MDCT							
Schlosser et al[41]	4*	0	100	100	NA	NA	NA
Song et al[45]	3*	0	100	96	0	83	97
Martuscelli et al[31]	20	12	100	100	0	90	100
Chiurlia et al[25]	15	1	100	100	0	95	100
Schuijf et al[43]	NA	0	96	100	14	100	96
Trigo Bautista et al[47]	28	16	92	97	NA	NA	NA
Salm et al[40]	NA	NA	NA	NA	9	100‡	93‡
Anders et al[15]	3*	0	100	98	22	80	85
Stauder et al[46]	1	0	98§	95§	NA	NA	NA
Burgstahler et al[16]	NA	0	100‖	100‖	NA	NA	NA
Bartnes et al[24]	0	25	69	99	24	33	98
Andreini et al[23]	6	0	100	99	0	100	99
64-Detector MDCT							
Pache et al[35]	4	0	100	100	0	75	96
Ropers et al[38]	3*	0	100	100	0	100	94
Meyer et al[32]	NA	2	100	97	0	91	97
Dikkers et al[26]	5	0	100	100	0	100	99
Jabara et al[28]	NA	0	93	100	0	100	100

B. MRI

Study (Author, Reference)	Time Between Tests (Mean, d)	Scan Sequence	MRI Technique	Occlusion detection, %		
				Unevaluable	Sensitivity	Specificity
1.5 T						
Aurigemma et al[50]	368*	Gradient refocused fast-scan cine MR	Cine	0	100†	88†
Wicke et al[63]	1	SE	Anatomy	0	73	73
Ambrosi et al[49]	7*	Ultrarapid MRI	MRA	0	92	90
Okamura et al [58]	NA	2D-FASTCARD	Cine	0	50	91
Vrachliotis et al[62]	1*	FISP-3D angiography	MRA	2.2	87	97
Von Smekal et al[61]	5,9	FLASH	MRA	14.6	100†‖	67†
Wintersperger et al[64]	0	3D radiofrequency spoiled fast low-angle shot	MRA	0	81	95
Kalden et al[55]	14*	HASTE	Anatomy	0	91†	96†
Boehm et al[51]	9	Ultrafast 3D GE	MRA	0	NA	94

(Continued on next page)

TABLE 2. *(Continued)*

B. MRI

Study (Author, Reference)	Time Between Tests (Mean, d)	Scan Sequence	MRI Technique	Occlusion detection, %		
				Unevaluable	Sensitivity	Specificity
Molinari et al[57]	15*	3D angiography with navigator echo	MRA	3.9	92‖	97
Engelmann et al[53]	0	3D radiofrequency spoiled fast low-angle shot	MRA	0	85	95
Wittlinger et al[65]	7*	HASTE	Anatomy	0	94†	95†
Ishida et al[54]	7*	FISP-3D	MRA	0	94†	95†
		Fast velocity encoding cine MR (peak flow)	VENC	8.3¶	86‖¶	88¶
		Fast velocity encoding cine MR (baseline flow)	VENC	8.3¶	86‖¶	94¶
		Fast velocity encoding cine MR (flow reserve ratio)	VENC	8.3¶	86‖¶	65¶
Vetter et al[60]	NA	3D radiofrequency spoiled fast low-angle shot	MRA	0	100	100
Wittlinger et al[66]	7*	HASTE	Anatomy	12.2	67	97
		3D angiography with navigator echo	MRA	9.8	78	97
Wittlinger et al[67]	NA	HASTE	Anatomy	0	88†	94†
		3D angiography with navigator echo	MRA	0	63†	75†
		FISP-3D	MRA	0	88†	94†
Bunce et al[52]	100,0*	True FISP	MRA	0	45†	84†
		3D-spoiled GE	MRA	0	73†	85†
Langerak et al[56]	NA	GE	Anatomy	6.2	61†	91†
Salm et al[59]	NA	TFEPI	VENC	19.3¶	62¶	82¶

*Maximum number of days.

†In article occluded grafts considered as negative and open grafts as positive. For consistency of the data, we reported here occluded grafts as positive and open grafts as negative.

‡Sensitivity and specificity based on segment analysis.

§Sensitivity and specificity calculated for both occlusion and stenosis detection.

‖Sensitivity and specificity calculated using all coronary bypass grafts, in article sensitivity and specificity for evaluable grafts reported.

¶Numbers given for stenosis detection instead of occlusion detection.

NA indicates not available; SE, spin echo; GE, gradient echo; FISP, fast imaging with steady-state precession; HASTE, half Fourier acquired single shot turbo spin echo; FLASH, turbo fast low-angle shot; TFEPI, Turbo field echo planar imaging sequence; NA, not available; VENC, velocity-encoded cine.

time of 4.8 years (range, 0.02–11 years) postoperatively were examined. In total, 64% venous bypass grafts and 36% arterial bypass grafts were included, with a median occlusion rate of 22% (range, 0%–60%). Sixteen articles reported details about the patient population: 9 articles included symptomatic patients, and 7 articles studied asymptomatic patients.

For MRI, the reported sensitivities for occlusion detection ranged from 45% to 100%, and specificities ranged from 65% to 100%. The number of excluded bypass grafts ranged from 0% to 19.3% (Table 2B). The overall 95% CI of DORs for MRI was 59 (Fig. 2B). Only 2 studies reported the diagnostic accuracy for stenosis detection.

Occlusion Detection

Overall sensitivity and specificity for MRI studies were 81% (95% CI, 76%–86%) and 91% (95% CI, 89%–93%), respectively. Studies using an MRA sequence with gadolinium (n = 8) performed better (sensitivity, 84% [95% CI, 75%–91%]; specificity, 93% [95% CI, 90%–96%]) compared with other MRI sequences (sensitivity, 79% [95% CI, 71%–86%]; specificity, 90% [95% CI, 87%–92%]).

Stenosis Detection

Only 2 MRI articles described an analysis of stenosis detection in bypass grafts using MRI.[54,59] One article used fast velocity-encoded cine MR images to measure the baseline blood flow volumes in internal mammary arterial grafts.[54] With a threshold value of 35 mL/min for baseline flow volume, the sensitivity and specificity for detecting bypass graft stenosis of more than 70% lumen diameter reduction were 86% and 94%, respectively. The second article evaluated MR velocity mapping with a fast breath-hold turbo field echo planar imaging sequence at rest and during stress.[59] Using 2.0 as cutoff value for coronary flow velocity reserve, sensitivity and specificity for detecting

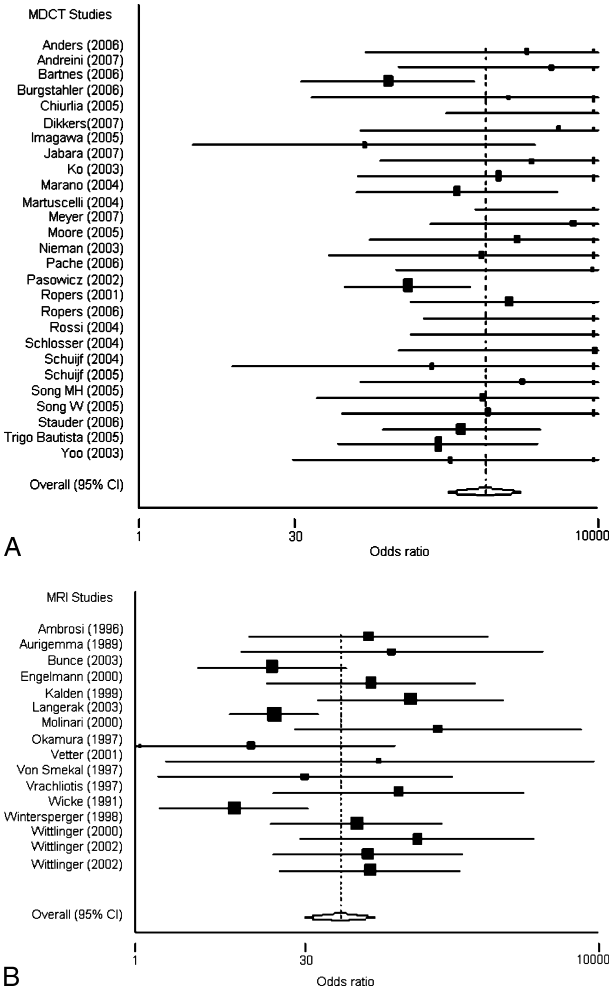

FIGURE 2. A, Summary DOR of included MDCT studies and (B) included MRI studies.

graft stenosis of more than 50% lumen diameter reduction were 62% and 82%, respectively.

Bivariate Analysis

A bivariate analysis of sensitivity and specificity as described by Reitsma et al[21] was performed for occlusion detection only. A significantly lower sensitivity was found in the MRI studies than in MDCT studies (81% vs 96%, $P < 0.001$). Specificity was also significantly lower for MRI compared with MDCT (91% vs 98%, $P < 0.001$). In a combined analysis including both sensitivity and specificity, a significantly lower diagnostic accuracy ($P < 0.001$) was found for MRI compared with MDCT. There was a negligible positive correlation between sensitivity and specificity in this combined analysis ($r = 0.02$).

In a second analysis, the studies evaluating the latest MRI scanning sequence (MRA with gadolinium) and latest MDCT scanners (16- and 64-slice CT) were included. The sensitivity and specificity of 1.5-T MRI scanners using MRA and gadolinium (84% and 93%, respectively) as a contrast agent ($P < 0.001$) were significantly lower compared with the sensitivity and specificity of studies published in the same period evaluating the diagnostic accuracy of MDCT studies using 16- and 64-slice MDCT scanners (96% and 98%, respectively). In the bivariate analysis, there was a strikingly low to absent correlation between sensitivity and specificity, which we could not explain.

DISCUSSION

This meta-analysis shows that detection of bypass graft occlusions with MDCT is significantly better than with MRI. Therefore, MRI for the single indication of bypass graft evaluation is not the technique of choice anymore. Magnetic resonance imaging has a high specificity (91%) and a moderate sensitivity (81%) for detecting bypass occlusions, whereas MDCT has both a significantly higher specificity (98%) and sensitivity (96%) for the noninvasive detection of bypass graft occlusion. For bypass graft stenosis assessment, even the most recent MDCT scanners show a rather moderate sensitivity of 89%.

Very few studies (n = 2) assessed the value of MRI for the detection of bypass graft stenosis, which can be seen as representative for the limited value of this technique in stenosis detection. An evaluation of bypass graft stenosis is actually not possible because of the low spatial resolution of MRI.[66]

Several authors have investigated time-of-flight and phase-contrast MRA as means of assessing coronary bypass grafts.[50,61,69,70] As a result of long data acquisition times required by both these techniques, respiratory and heart motion-generated artifacts led to an unsatisfactory image quality that reduced the accuracy of the method. More recent studies investigated spin echo sequences to obtain morphological information. It is also possible to assess bypass function by means of gradient echo and spin echo sequences. Gradient echo sequences have the advantage to be less susceptible to metal artifacts. Another important limitation of noninvasive CAG using MRI is that, besides the limited field of view, the signal-to-noise ratio limits the trade-off between time and spatial resolution. With the new 3.0-T systems, which are now available for clinical use, signal-to-noise ratio in coronary applications improves spatial and time resolution permitting visualization of longer segments of coronary arteries and bypass grafts.[71] This new technique will also result in a shorter scan time and shorter breath-hold with consequently improved patient cooperation.[71] The significant increase in image quality acquired at 3.0 T compared with 1.5 T comes, however, at the expense of susceptibility artifacts.[72]

Seventeen of the 28 studies assessed the value of MDCT for stenosis detection. The reported sensitivities and specificities were acceptable (89% and 97%, respectively). The pooled sensitivity for stenosis detection improved a little for studies using 16- and 64-slice MDCT scanners. In the detection of coronary artery disease, it has been shown that both the number of assessable native segments as well as sensitivity for the detection of coronary artery stenosis improved with increasing numbers of slices used (ie, 74% and 76% for 4-slice MDCT and 97% and 92% for 64-slice MDCT).[73] Despite the improved spatial and temporal resolution of these scanners, severe calcifications and metal clips still result in blooming artifacts. Quantification of stenosis in severely diseased vessels, as is the case in post-CABG patients, is therefore still challenging.

One recently published meta-analysis compared the diagnostic accuracy of MRI and MDCT for the noninvasive detection of (native) coronary artery stenosis in patients suspected of having coronary artery disease.[74] In those patients, significantly more coronary segments could be evaluated with MDCT than with MRI, and a significantly better sensitivity and specificity for detecting coronary artery stenosis were found. Our current meta-analysis of the noninvasive evaluation of CABG underlines the superiority of MDCT over MRI.

It is known that both techniques require a regular heart rhythm, and image quality is reduced by the presence of surgical clips. Magnetic resonance imaging, however, has the potential to overrule CT as a noninvasive alternative to CAG because it can combine morphological imaging with functional parameters such as flow measurements without the use of x-ray exposure. Magnetic resonance imaging has the potential to point out the stenosis and, in addition, assesses the presence or absence of ischemia. Especially MR first-pass perfusion imaging and stress-induced wall motion abnormalities have been proven to reliably assess the presence of ischemia in a high-risk population both at the patient level and at coronary territory level.[75] A recent study estimated a 3-year event-free survival of 99% for patients with a normal MR perfusion and dobutamine stress MR in patients with known coronary artery disease.[76] This allows MRI to select grafts in need of further invasive analysis and revascularization to alleviate myocardial ischemia. Despite these benefits, the visualization of the coronaries and bypass grafts still largely differs between MDCT and MRI, and MRI needs new approaches, contrast media, and hardware improvements to compete with MDCT again.

X-ray exposure has only a very limited role in the selection of the technique of choice for bypass graft evaluation because it concerns the older patient population. Based on our results, MDCT would be superior to MRI for the noninvasive evaluation of bypass graft disease. Only in patients scheduled for an MR stress test (ie, MR perfusion or dobutamine stress MR) that MRI can be used for bypass graft occlusion assessment in a one-stop-shop procedure. In case of inconclusive results, evaluation with MDCT or CAG will still be indicated.

A limitation of the validity of any meta-analysis is publication bias. Smaller studies, and especially those with negative results, are less likely to be accepted for publication than larger studies, leading to an overestimation of the diagnostic accuracy of a test when combining only published reports. In this meta-analysis, publication bias is suspected for MRI and MDCT studies. We therefore acknowledge the potential overestimation of the pooled sensitivity and specificity for both MRI and MDCT, but because both techniques seem to suffer from publication bias, the difference between MRI and MDCT can be expected to be real.

CONCLUSION

Multidetector computed tomography is superior to MRI for noninvasive detection of coronary bypass graft occlusion and stenosis. Only in patients with an additional indication for MR perfusion, wall motion, or stress testing that bypass graft occlusion could be evaluated using MRI. For the single indication of bypass graft evaluation, MRI is not the technique of choice anymore.

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